Technologies & growth: handling the paradox of productivity

Thought Leadership

Atos

Trusted partner for your **Digital Journey**

Contents

Businesses and society are witnessing dramatic change, enabled by the technological innovations. Modern trends are replacing each other at a rapid speed. Meanwhile, economic growth and aggregated productivity statistics are static, resistant to these disruptive changes.

This paper explores the main constraints on productivity growth, despite the potential opportunities represented by emerging technologies. Among these constraints are the natural selection of innovations, uneven allocation of resources, a lack of human capital to meet all technological needs and requirements, and coordination failures. Because technological innovations are intended to boost firms' productivity and ultimately enhance economic growth, it is critical to explore all these constraints. Based on our analysis, we propose implementing cost tracking as well as organizing innovations into connected portfolios to increase the ratio of natural selection of innovations. We also recommend embracing data sharing and coordinating investments, including industrial investments and investments in human capital.

About the Atos Scientific Community

The Atos Scientific Community aims at crafting the Group's vision for the future of technology in business, and anticipating the upcoming trends and technologies that will reshape businesses and society in the years ahead.
This global network comprises 160 of the top scientists, engineers and forward thinkers from across the Group, with a rich mix of skills and backgrounds.

Author & Acknowledgements

Anna Borodina, economist, Atos Scientific community member.
The author would like to thank the Atos Scientific Community, and notably the following members for their valuable comments: Peter Vrenken, John Hall, Jose Esteban Lauzan, Thierry Caminel, Ivo Luijendijk, Peter Kalmijn, Paul Albada Jelgersma, Claire Unwin.

Introduction

Society has experienced several transformative waves of innovation in recent decades. Personal computers, enterprise software, the Internet and mobile broadband, smartphones and apps, big data and IoT, smart devices and sensors, predictive analytics, virtual reality, drones, autonomous vehicles, automation, robotics and artificial intelligence are only some of the innovations that have re-shaped our society since the 1960s and continue to do so today.

The overwhelming majority of these technologies are an essential part of modern businesses and our everyday lives. AI-related technologies are demonstrating remarkable progress in component development. Image recognition technology has improved from an error rate of 25% to less than 5%[1] in less than 6 years.
In the abstract strategy games domain, computer chess has already exceeded the best human beings in terms of the Elo rating system. Since 2017, the word error rate for speech recognition technology has dropped below the 6% threshold, compared to an error rate greater than 16% in 2012. The ability of machines to discern instrumental music from vocal music has improved to nearly 80% correct recognitions, compared to a rate less than 20% in 2013[2].
Such rapid progress represents wonderful opportunities to enhance business prosperity and advance the welfare of society.
It is expected to stimulate firms' productivity and ultimately enhance economic growth.

However, the reality is quite different. Our findings imply that technological change has not materialized into a breakthrough in aggregate productivity and growth – despite the noticeable progress which served as a catalyst for the prosperity of tech giants and a destructor for less innovative and adaptive market players.
This paper seeks to bridge the productivity paradox[3] which takes place at the macro scale. The activities of industrial markets and firms (R&D efforts, technology diffusion and adaption, resource distribution, etc.) serve as total factor productivity (TFP) enablers that are significant factors in addressing this challenge from an economy-wide perspective. We will explore the possible explanations of the productivity paradox as well as provide some recommendations for how firms and industries can tackle this problem.

[1] https://www.eff.org/ai/metrics
[2] https://www.eff.org/ai/metrics
[3] The "productivity paradox" idea was first formulated by R. Solow in 1987. At that time, the phenomenon was referred to as a "computer paradox" unique to the 20th century, where the expected increase in efficiency was observed everywhere but in productivity and GDP statistics. The idea was further developed by E. Brynjolfsson, P. P. Strassman, S. Roach and others, primarily focusing on the US economy. In today's world, it appears that the same thinking is still valid, but at a global scale and no longer solely for the US economy.

Innovations and aggregated productivity statistics

Economic growth is a complex and multidimensional phenomenon. Its causes are diverse and differ across countries. The volume of economic output is sensitive to cyclical fluctuations driven by technological change, social and economic expectations, financial or monetary shocks, wars and pandemics. Despite these fluctuations, it is still important to find a balance that mitigates gross domestic product (GDP) declines and enables the fastest possible recovery after a recession. In this context, innovation serves both as a mechanism of growth and as a powerful catalyst for economic recovery.

From an economic theory perspective, it's important to note that the pioneering works in both the exogeneous and endogenous growth models postulate that innovation-related activities have a positive impact on economic growth predictions. By way of definition, exogenous growth theory considers technological progress to be the primary driving force for sustainable growth[4]. In contrast, endogenous growth theory maintains that growth is driven by R&D activities[5] or through the accumulated stock of knowledge and ideas[6]. In general, endogenous models can be divided into two groups:

- Models with horizontal innovations (Romer 1987[7]), which place special emphasis on the idea of monopolistic competition in the R&D sector
- Models with vertical innovations, which follow a Schumpeterian approach (Aghion, Howitt, 1992[8]; Grossman, Helpman 1991a,1991b[9]) with regards to creative destruction

The themes and ideas presented in these papers coincide quite closely with the reality we have witnessed in recent years. The idea of monopolistic competition in the R&D sector is analogous to the "winner takes it all" game practiced by today's tech giants. From a societal welfare perspective, this is something that must be accepted, as such monopolistic behavior creates both incentives for innovators and positive spillovers for society. The Schumpeterian approach argues that technological innovation has not just a bright side, but also a dark side — which is represented by the destruction of many established firms that were unable to survive against disruptive changes. This idea is also aligned with the very real phenomenon of so many firms and SMEs disappearing from the market or being absorbed by stronger market players.

Both types of model emphasize the extreme importance of human capital in the success of the innovation process and economic growth, which is a "top of mind" issue for today's political and business leaders. Only the empirical evidence of endogenous growth theory remains disputable because — in contrast to these models' predictions — GDP growth rates are quite stable.

If we compare the average growth rates of GDP per capita with labor productivity and total factor productivity for some Western economies (USA, UKI, Germany, France, Belgium, Netherlands, Spain, Italy) for the 2000-2019 period (figure 1), we must conclude that aggregate macroeconomic indicators are quite stable within the given interval. The productivity growth rates have not exceeded 3%, even after the 2008 financial crisis.

Figure 1: The dynamics of GDP per capita, labor productivity and total factor productivity for the period 2000-2019[10]

[4] Solow R. (1957). Technical change and the aggregate production function. Review of Economics and Statistics, Vol. 39, No. 3, pp. 312—320.
[5] Aghion, Philippe and Peter Howitt, "A Model of Growth through Creative Destruction," Econometrica, March 1992, 60, 323-351
[6] Romer P. (1990). Endogenous technological change. Journal of Political Economy, Vol. 98, No. 5, pp. 71—102.
[7] Romer P. M. Crazy explanations for the productivity slowdown. NBER Macroeconomics Annual, MIT Press. 1987.
[8] Aghion P., Howitt P. A model of growth through creative destruction. Econometrica, v. 60, p. 323-351. 1992.
[9] Grossman G. M., Helpman E. Innovation and growth in the world economy. MIT Press. 1991a; Grossman G. M., Helpman E. Quality ladders in the theory of growth. Review of Economic Studies, v. 58, p. 43-61. 1991b.
[10] Conference board author's calculations. Here is the average dynamics of GDP per capita, labor productivity and total factor productivity, calculated for the Western countries (USA, UKI, Germany, France, Belgium, Netherlands, Spain, Italy).

Thus, the effects of digital technologies are not yet explicitly observable through aggregate macroeconomic indicators. These results beg the question whether the situation is different in "digitally savvy" locations. For example, what happened in the most innovative areas in Silicon Valley in terms of changing the world?

"If Silicon Valley were a country, it would be among the richest on Earth."

The Guardian, April 30, 2019

If one compares the GDP per capita growth rate of the San Jose, CA Metro area against the top 5 world economies ranked by their GDP per capita income, the result is remarkable (table 1). The growth in this particular area in Silicon Valley significantly exceeded that of the world's top 5 richest economies. No country among those with the highest 2019 income per capita exhibited growth as large as the San Jose Metro area. The only country that managed to even come close to San Jose's 73.5% growth rate was Singapore — which grew by 67%. As for the other 4 countries, they lost this race by a long shot within the observed period. This occurred because San Jose has exceeded the 6% GDP per capita growth threshold, even after the 2008 financial crisis.

Table 1: GDP per capita growth rates (for the period from 2001 to 2017)[11]

Country/Area	GPD per capita income, 2019 (in 2018 USD)	GDP per capita (%)
Qatar	$140,156	6.8%
Luxembourg	$103,783	12,5%
Singapore	$93,440	67%
United Arab Emirates	$77,991	-31,7%
Norway	$74,345	10,2%
San Jose, CA USA	**$128,308**	**73,5%**

Basically, this confirms that higher productivity growth rates driven by technological progress are possible, but — unfortunately — such cases likely to be exceptions that only serve to affirm the "winner takes all" situation. The main reason for such a unique case is a strong concentration of firms that have attained technological leadership in their respective fields. To us, the more important questions are: "What is holding others back?" and "How can the productivity paradox be explained?"

[11] Conference board, Open data network, author's calculations

Explaining a productivity paradox

As mentioned earlier, the productivity paradox is not a new phenomenon. The stagnation in productivity growth rates and explanations of the "Solow paradox" are the subject of research in papers by E. Brynjolfsson, A. Agrawal, J. Gans, A. Goldfarb and others.
For the economists[12] mentioned above, the following reasons could serve as the main constraints on productivity growth despite the progress of digitalization:

False hopes

Regarding the future success and influence of newly introduced technologies

GDP mismeasurement issues

This problem was also explored by Mokyr[13], Alloway[14], Feldstein[15], Hatzius & Dawsey[16], and Smith[17]. This kind of issue happens because "the technologies might deliver substantial utility, even if they account for a small share of GDP due to their low relative price."[18]

Implementation and restructuring lags

It takes time for technologies to evolve, meaning that there is always a lag between when technology enters the market and when it is successfully adopted. This is also underpinned by empirical evidence. For instance, in one of the papers by Comin[19], a diffusion analysis for 15 technologies from 166 countries was conducted for the period from 1820-2003. The most interesting finding was the average period of time required to adopt the technology. Comin's analysis revealed that full adoption came an average of 45 years after the invention of a new technology. The transformation of business models and people's everyday way of life also experience a certain lag period following successful commercialization.

Concentrated distribution and rent dissipation

In other words, this is a situation when most of the benefits are concentrated in the hands of small group of tech giants that are not willing to give their market share to other players. Consequently, it leads to a significant increase in the gap between large and small firms in terms of profit margins.

All the reasons set forth above are valid, but require clarification and additional exploration outside the scope of this paper. For example, despite all the shortcomings of GDP measurement, the gross volume of output provided by just one area in Silicon Valley produced a result that exceeds the leading economies of the world. So, what else is constraining productivity gains?

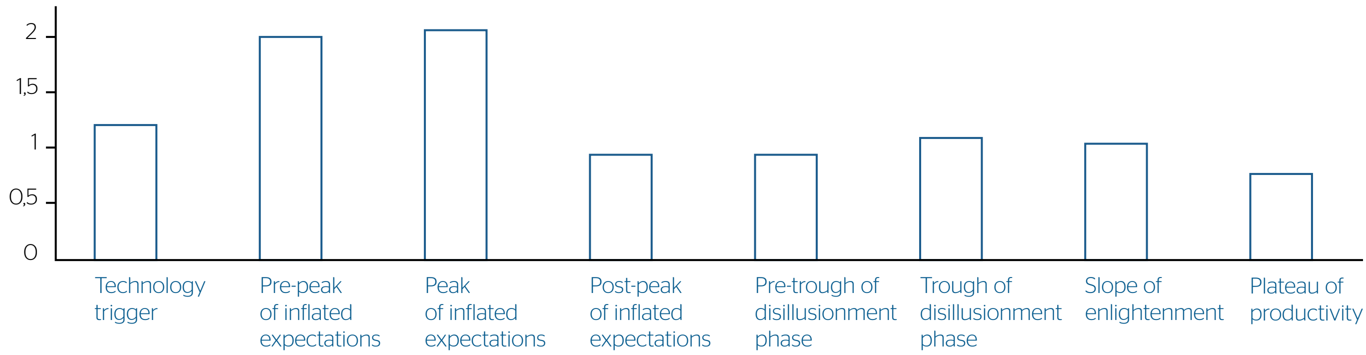
[12] Agrawal A, Gans J., Goldfarb A. The Economics of Artificial Intelligence: An Agenda (2017)
[13] Mokyr, J., Secular stagnation? Not in your life. Secular stagnation: Facts, causes and cures (2014), 83
[14] Alloway, Tracy, "Goldman: How 'Grand Theft Auto' Explains One of the Biggest Mysteries of the U.S. Economy." Bloomberg Business, May 26, 2015. http://www.bloomberg.com/news/articles/2015-05-26/goldman-how-grandtheft-auto-explains-one-of-the-biggest-mysteries-of-the-u-s-economy
[15] Feldstein, Martin, "The U.S. Underestimates Growth." Wall Street Journal, May 18, 2015
[16] Hatzius, Jan and Kris Dawsey. (2015). "Doing the Sums on Productivity Paradox v2.0." Goldman Sachs U.S. Economics Analyst, No. 15/30
[17] Smith, Noah. (2015). "The Internet's Hidden Wealth." Bloomberg View, June 6. http://www.bloombergview.com/articles/2015-06-10/wealth-created-by-theinternet-may-not-appear-in-gdp.
[18] Agrawal, Gans and Goldfarb, The Economics of Artificial Intelligence: An Agenda
[19] Comin D. and Hobijn B, An exploration of technology diffusion (American Economic Review, 2010), 100 (5), 2031–59

Natural selection

The first objective constraint to include in this list is natural selection or survival of the fittest. In other words, how does a new technology swim out of the "Darwinian sea of innovations?"[20].
This is the technology diffusion process, implying the evolution of any technology's maturity. Analyzing the relative frequency distribution of technologies in Gartner's curve hype cycles (figure 2) for the 20 years from 2000 to 2019, we must recognize that only a few technologies have passed the "trough of disillusionment" stage and reached the "plateau of productivity" (8%, or just 19 technologies).

The anticipated modal value of 20% stands at the "peak of inflated expectations" phase, meaning that most technologies never progress beyond this stage. We need to recognize that only 11% reach the "trough of disillusionment" level of maturity and fewer still (8%) become a real commercialized product that has managed to find its customer and catch the attention of a critical mass. This is evidence of the substantial heterogeneity related to technology diffusion.

Figure 2: The relative frequency distribution of technologies found on Gartner's curve [21]

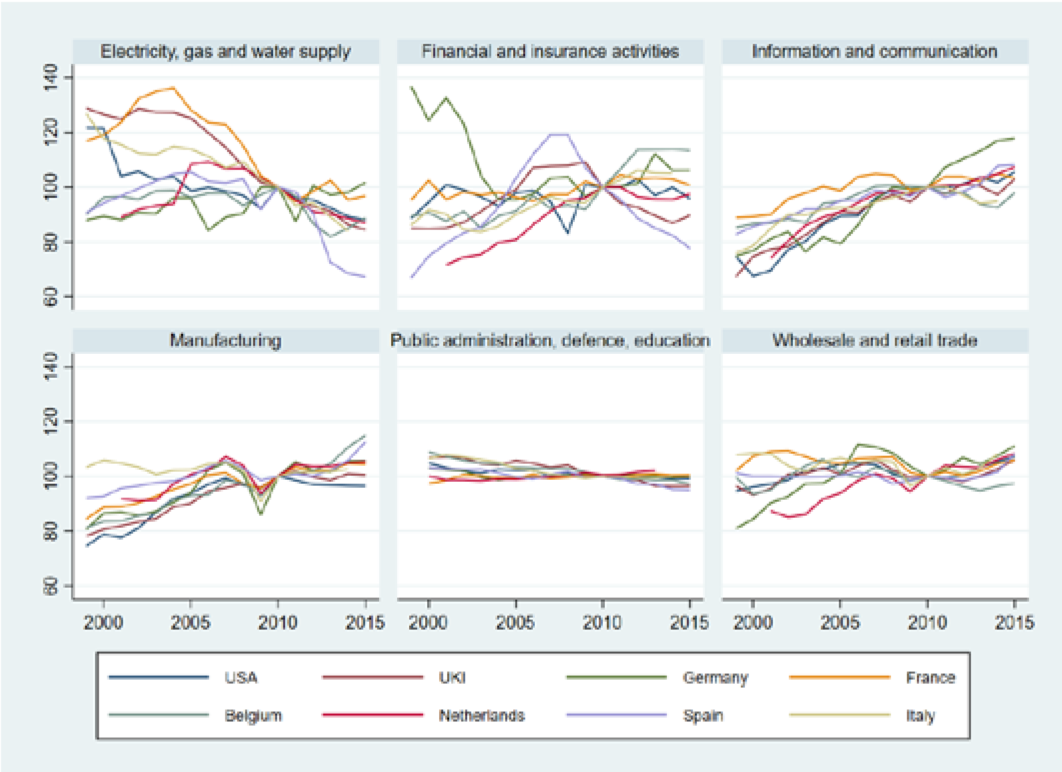


Uneven redistribution of resources

The second constraint to be mentioned is the uneven redistribution of resources. Because the advent of new technologies entails a redeployment of inputs, it is reasonable to anticipate productivity growth in some industries and a decline in others. These opposing effects counterbalance the output. If one compares the dynamics of TFP among different industries in some EU countries and the US from the 1990s until 2015, it is easy to identify these opposite effects. Below, we will compare TFP for a select group of industries in greater detail (figure 3).

[20] The term "Darwinian sea of innovations" belongs to https://www.nist.gov/system/files/documents/2017/05/09/gcr02-841.pdf
[21] Author's calculation based on data from Gartner Research, Inc. The phases "pre-peak of inflated expectations," "post-peak of inflated expectations" and "pre-trough of disillusionment phase" have been added by the author.

Figure 3: TFP dynamics per industry for the period from 2000 to 2015[22]



The first observation is the productivity in the financial services and insurance sector. Among observable countries, the US, UKI, France, Belgium, Netherlands, Spain and Italy exhibited efficiency growth within this industry. Meanwhile, the 2008 financial crisis was explicitly observable via a dramatic reduction of productivity in the US financial sector. A significant productivity slowdown was also noticed in Germany, where the financial sector experienced a substantial decrease after 2000. The financial sector's major hopes were linked to the integration of technologies into financial services and developing so-called "Fintech" companies in order to provide the industry's transformation.

There were many more efficiency cases recorded in manufacturing. This sector experienced a significant increase in productivity among the selected countries within this time frame. The cause may have been the technological shocks the industry experienced in the preceding decades, including Industry 4.0 for example.

Along with manufacturing, the information and communication and wholesale and retail trade industries also experienced productivity increases.

A stagnation of efficiency growth rates in public administration, defense and education sector could be explained by the time required for technology adoption.

The dramatic productivity decline in electricity, gas and water supply is a completely different story. Such a situation indicates that the industry has already experienced its peak in efficiency. Here, the most realistic scenario for success is to restructure the economy (especially for commodity-heavy economies) or to pursue decarbonization to improve efficiency through innovations in sustainability.

[22] Author's calculations; KLEMS database

Human capital

Human capital also plays a key role in technological success. A mismatch between skills and technologies is one of the major challenges that society has faced with the arrival of digitalization. Technological change and all the associated transformations have caused dramatic shifts in labor demand. COVID-19 has significantly accelerated the simmering issue. Many of the leading tech giants[23] have announced[24] hundreds of millions of dollars[25] in investments to retrain and upskill the existing workforce. Today, private companies and governments are already taking action in an attempt to resolve the problem of a mismatch between skills and technologies highlighted by D. Acemoglu[26] and P. Restrepo. Such actions are aimed at developing the skills to complement existing and emerging technologies in order to boost productivity and prevent the stifling of growth. The incentive to resolve the mismatch between skills and exploit new technologies such as virtual reality and the platform economy may pave the way for the transformation of "traditional" sectors and subsequently, productivity growth.

Coordination failures

One more crucial reason to be highlighted here is about coordination failures, especially due to the entanglement and uncertainty that accompanies the innovation process. As one of the greatest economists of the twentieth century, K. Arrow stated[27]:

> "The notion of the inner coherence of the economy – the way markets and the pursuit of self-interest could in principle achieve a major degree of co-ordination without any explicit exchange of information, but where the results may diverge significantly from those intended by the individual actors – is surely the most important intellectual contribution that economic thought has made to the general understanding of social processes."

According to Arrow, unexploited resources are a great example of a coordination failure. Data is a typical example of just such a resource in the modern economy. Digitalization has brought with it many public goods which are openly available by nature (now termed as "non-rival").

The most precious among these goods is data, which was aptly called the "fuel" of the digital economy by Andrea Di Maio (Managing Vice President at Gartner Research) and the "new oil" by H. Varian (Chief Economist at Google). Today, data that could be productively used at low business and social cost by many others (like people, businesses and third parties) is not made available. 53% of all firms hoard data[28], fearing a risk of creative destruction or for other reasons.

Thus, this accumulated but unused potential stock of knowledge is not exploited.

It is also highly possible that some technologies are still being developed and their effect will be seen farther in the future. It takes time to evolve, and there is a lag between when technology enters the market and when it is broadly adopted. It might take decades, especially for general purpose technologies like electricity and steam engines in the past, and AI today.

It is a natural process that requires time to evolve, and only can the effects be measured. If the time factor is significant but difficult to influence, what could be done to reap more immediate benefits from technologies? Companies pursuing an R&D strategy can choose whether to hasten the process of innovation, focus on the optimal allocation of resources, or place more emphasis on the process of adoption and diffusion of new technologies.

Within our recommendations, we have focused on the importance of the technology implementation and adoption process. All the actions should be aimed at enhancing coordination and cooperation among market players.

[23] https://www.techradar.com/news/microsoft-google-launch-initiatives-to-help-workers-reskill-for-post-pandemic-world
[24] https://www.fastcompany.com/90380050/amazon-upskilling-100000-employees-and-the-future-of-work
[25]https://www.chieflearningofficer.com/2019/07/11/amazon-goes-big-with-700-million-reskilling-pledge/#:~:text=Amazon%20announced%20on%20Thursday%20it,over%20the%20next%20six%20years.&text=With%20nearly%20300%2C000%20employees%20and,employers%20in%20the%20United%20States.
[26] Acemoglu D. Artificial Intelligence, Automation and Work / D. Acemoglu, P. Restrepo. – National Bureau of economic research, 2018
[27] Arrow K. J. Economic Welfare and the Allocation of Resources for Invention / K.J. Arrow. – Collected Papers of Kenneth J. Arrow. – Vol. 5. Cambridge : Harvard University Press
[28] Forrester, author's calculations

Recommendations

Implement cost tracking

First, let's explore proper cost tracking on the subject of innovation potential. It should be efficiency in costs adoption: costs to know what technology is needed to produce a required good or service and how to use it individually or as a part of an existing process. It's also about finding and understanding the nature of pricing for technologies, products and services which are or may be complementary (such as lithium ion batteries and electric vehicles, or computers and the Internet in the use cases mentioned below).

This is a fundamental point in helping innovations survive and be successfully commercialized to meet the needs of customers. There are many products available today simply because their components have become cheaper. One good example for this case is the market for hybrid electric vehicles. Thanks to a reduction in the price of lithium ion batteries (mainly due to the emergence of new technologies and production process improvements), it became possible to produce mass market electric vehicles at an affordable price.

In his research, Gordon[29] clustered the greatest inventions from 1860 to 1900 and demonstrated how their development and diffusion in the 19th century led to the fundamental transformation of Americans' life standards at the end of 20th century. According to the author, the introduction of the Internet didn't promote growth in demand for computers. Conversely, a reduction in the price of computers became the reason for the increased popularity of the Internet.

Nowadays, business and society have pinned their hopes on AI and the opportunities to which it can lead. One significant factor that makes these hopes realistic is the reduced price of prediction that AI can deliver. Predictive analytics today is a promising area for any company, yet implementing such an idea in the past would have involved considerable costs. For instance, Amazon obtained a patent for "anticipatory shipping" in 2013[30], implying that Amazon may someday switch to a "ship then shop" business model in which products could be sent to consumers before they are even ordered.

Today, Amazon still uses a "shop then ship" business model, but once it has more data available to make cheaper and more accurate predictions, the adoption of the new strategy will not be long in coming. According to this scenario, people may never need to visit a physical shop again.

Organize innovations in connected portfolios

Another important action to take is to create a map of digital technologies, or a coupled system of complementary innovations which together might provide a successful product or service. This is a technology portfolio organization technique that can enable the monitoring of all possible combinations of symbiotic innovations. It is also a real opportunity to maximize the number of possibilities for new product or service creation. Organizing related innovations is even more important for general purpose technologies (e.g. steam engines, electricity, AI) which themselves are already a combination of technologies. Having a clear vision of how one innovation can complement or contribute to the survival of another is a strong enabler of technology creation and commercialization.

Embrace data sharing

The next response to the paradox is related to data and all the opportunities it provides. The processes of data sharing and standardization could be a trigger for new innovations and effective knowledge management at all levels. Data (as a by-product) might also be a complement which could be successfully applied to assets such as labor and capital to bring positive returns to scale[31] due to its' non-rival nature. From an economic point of view, the non-rivalry of data leads to significant social benefits when the same data can be used by several firms at the same time. In contrast, siloed data could serve as a barrier that leads to market failures — reinforcing information asymmetry instead of acting as an infinitely and commonly usable productive force.

Coordinate investments globally

The last powerful instrument to be mentioned here is the coordination of investments. Special attention should be paid to industrial investments and to investments in complementary technologies. Meanwhile, the simplest way to upgrade a technology inside one's country today is to obtain access to the best technologies already existing in the market. Due to high costs, significant R&D expenditures are becoming a lower priority for many governments and companies. Thus, it becomes a privilege for advanced economies to be pioneers at the frontier of new technology creation, reinforcing their advancement. Meanwhile, cooperation and coherence around investments is a powerful instrument to achieve more.

[29] Gordon R. Does the "New Economy" Measure up to the Great Inventions of the Past? https://econpapers.repec.org/paper/nbrnberwo/7833.htm
[30] https://www.smartdatacollective.com/amazon-wants-predictive-analytics-offer-anticipatory-shipping/
[31] Jones C.I. Nonrivalry and the Economics of Data / C.I. Jones, C. Tonetti. – Stanford GSB and NBER, 201

Conclusion

Our modern economy is experiencing a slowdown in growth, and there is more than just a pandemic behind it. This question "why is this happening?" has yet to be answered. However, situations like this underscore the importance and wisdom of studying the lessons of the past.

What these lessons reveal is modest growth with insignificant ups and downs in some countries, and prosperity and extreme success for others — especially smaller locales. The latter example is characterized by a huge share of venture capital and an excellent ecosystem that has been created. The example of Silicon Valley discussed above is more than just illustrative. We have also observed that these locales are also characterized by a faster recovery rate after the deepest crises. As we observed after 2008, they reached far lower lows than other areas, yet experienced a faster recovery. The role of natural selection in the evolution of innovations is also a crucial one. The reality is that only about 8% of all technological breakthroughs are successfully commercialized.

This fact serves to confirm the entanglement and uncertainty that accompanies the innovation process. The innovation process is also about redeployment of resources. As practice shows, technologies affect industries differently.

The hallmarks of modern digital technologies are rapid changes, high degrees of uncertainty and almost zero replication, verification, transportation and information search costs. Digital technologies can simplify and increase the speed of interaction with clients, the efficiency of business processes, and broaden the possibilities for creating ecosystems.

The opposing factors include the opportunity costs of not using digital technologies, staff retraining, significant increases in the cost of introducing new technologies, and higher levels of competition i n the market. These conflicting effects are extremely uneven and chaotic.As pointed out above, TFP changes in different industries were multidirectional. Digitalization has given "new oil" to the society in the form of data.

As a key component of many promising and emerging technologies, data plays an enormous role as a complementary good (enabling technology survival) and as a source of knowledge. Therefore, it is extremely important to find the right approaches to data operations, which are based on frictionless knowledge sharing and standardization. It bears mentioning that in so doing, it is possible to achieve inner coherence and coordination among all game players.

The collective thinking and consensus of all the dedicated actors (businesses, societies and governments) combined with the ability to adapt to new circumstances should be the drivers of successful technological development — despite implementation lags, the natural selection of innovations, inefficiencies around data, mismatch between skills and technologies, randomness and uncertainty that accompany the invention and implementation of new technologies.

References

1. Acemoglu D. Artificial intelligence, Automation and Work / D. Acemoglu, P. Restrepo. – National Bureau of Economic Research, 2018

2. Agrawal A, Gans J., Goldfarb A. The Economics of Artificial Intelligence, 2017. – https://www.nber.org/papers/w24001.pdf (accessed: 1.10.2018)

3. Arrow K. J. Economic Welfare and the Allocation of Resources for Invention / K.J. Arrow. – Collected Papers of Kenneth J. Arrow. – Vol. 5. Cambridge: Harvard University Press.

4. Bresnahan, T. F., E. Brynjolfsson, and L. M. Hitt (2002, February). Information technology, workplace organization and the demand for skilled labor: Firm-level evidence. The Quarterly Journal of Economics 117 (1), 33-76

5. Solow R. (1957). Technical change and the aggregate production function. Review of Economics and Statistics, Vol. 39, No. 3, pp. 312—320

6. Diamond P. (1965). National debt in a neoclassical growth model.American Economic Review, Vol. 55, No. 5, pp. 1126—1150.

7. Romer P. (1990). Endogenous technological change. Journal of Political Economy, Vol. 98, No. 5, pp. 71—102

8. Negroponte N. Being Digital/ N. Negroponte – New York: Alfred A. Knopf, Inc.; Vintage Books, 1996

9. Gordon R. Does the "New Economy" Measure up to the Great Inventions of the Past? – https://econpapers.repec.org/paper/nbrnberwo/7833.htm

10. J. A. Schumpeter "The Theory of Economic Development" – https://www.hup.harvard.edu/catalog.php?isbn=9780674879904)

11. Mokyr, J. (2014). Secular stagnation? Not in your life. Secular stagnation: Facts, causes and cures, 83

12. Alloway, Tracy. 2015. "Goldman: How 'Grand Theft Auto' Explains One of the Biggest Mysteries of the U.S. Economy." Bloomberg Business, May 26. http://www.bloomberg.com/news/articles/2015-05-26/goldman-how-grandtheft-auto-explains-one-of-the-biggest-mysteries-of-the-u-s-economy

13. Feldstein, Martin. (2015). "The U.S. Underestimates Growth." Wall Street Journal, May 18

14. Hatzius, Jan and Kris Dawsey. (2015). "Doing the Sums on Productivity Paradox v2.0." Goldman Sachs U.S. Economics Analyst, No. 15/30

15. Smith, Noah. (2015). "The Internet's Hidden Wealth." Bloomberg View, June 6. http://www.bloombergview.com/articles/2015-06-10/wealth-created-by-theinternet-may-not-appear-in-gdp.

16. Comin D., Hobijn B. (2010) An exploration of technology diffusion. American Economic Review, 100 (5), 2031-59

17. Jones C.I. Nonrivalry and the Economics of Data / C.I. Jones, C. Tonetti. – Stanford GSB and NBER, 2018

About Atos

Atos is a global leader in digital transformation with 105,000 employees and annual revenue of over € 11 billion.

European number one in cybersecurity, cloud and high performance computing, the Group provides tailored end-to-end solutions for all industries in 71 countries. A pioneer in decarbonization services and products, Atos is committed to a secure and decarbonized digital for its clients. Atos operates under the brands Atos and Atos|Syntel. Atos is a SE (Societas Europaea), listed on the CAC40 Paris stock index.

The purpose of Atos is to help design the future of the information space. Its expertise and services support the development of knowledge, education and research in a multicultural approach and contribute to the development of scientific and technological excellence. Across the world, the Group enables its customers and employees, and members of societies at large to live, work and develop sustainably, in a safe and secure information space.

Find out more about us
atos.net
atos.net/careers

Let's start a discussion together

The Atos Scientific Community crafts the Group's vision for the future of technology in business, and anticipates the upcoming trends and technologies that will shape businesses and society in the years ahead.

For more information: atos.net/scientific-community

Atos, the Atos logo, Atos | Syntel and Unify are registered trademarks of the Atos group. June 2021 © Copyright 2021, Atos S.E. Confidential information owned by Atos, to be used by the recipient only. This document, or any part of it, may not be reproduced, copied, circulated and/or distributed nor quoted without prior written approval from Atos.

CT-210608-RY-J3388-ATOS-WP-TECHNOLOGIES